Bremsstrahlung Photons as a Probe of Stopping in Pb+Pb Collisions at the LHC?

Stopping Workshop

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Aaron Angerami and
Brian Cole
Columbia University

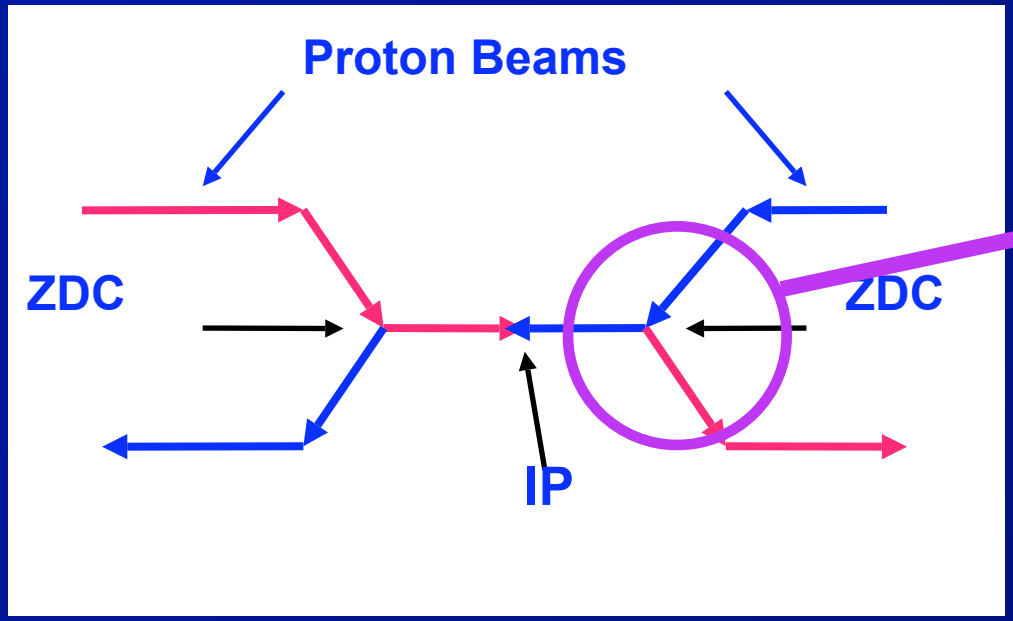
Motivation

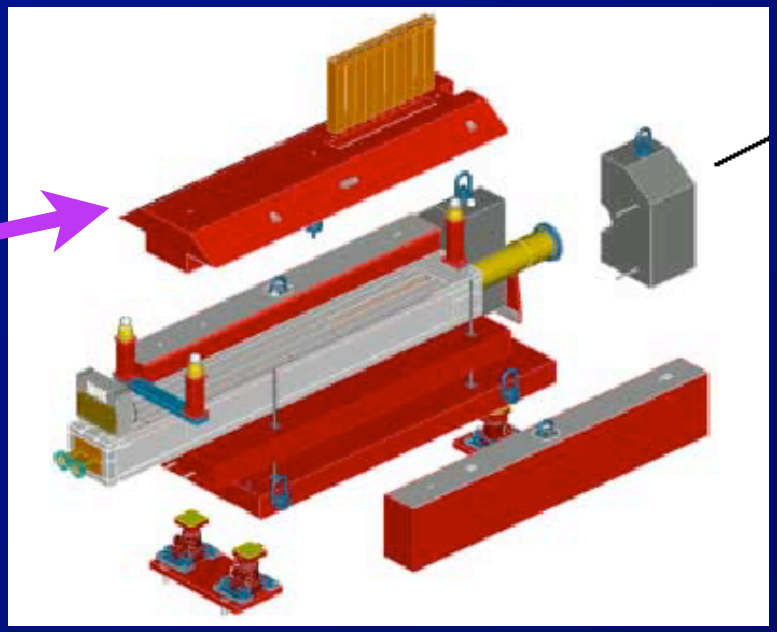
- **Primary motivation:**
  - Running discussionn/argument with Peter re: Landau Hydro
    - ⇒Do the Landau initial conditions make sense at RHIC (and LHC?) energies?
    - ⇒Can it be that everything stops and gets re-acceleerated?
  - How to test radically different pictures of initial physics?
- **Better:**
    - ⇒how to provide different experimental insight on physics of "stopping"?

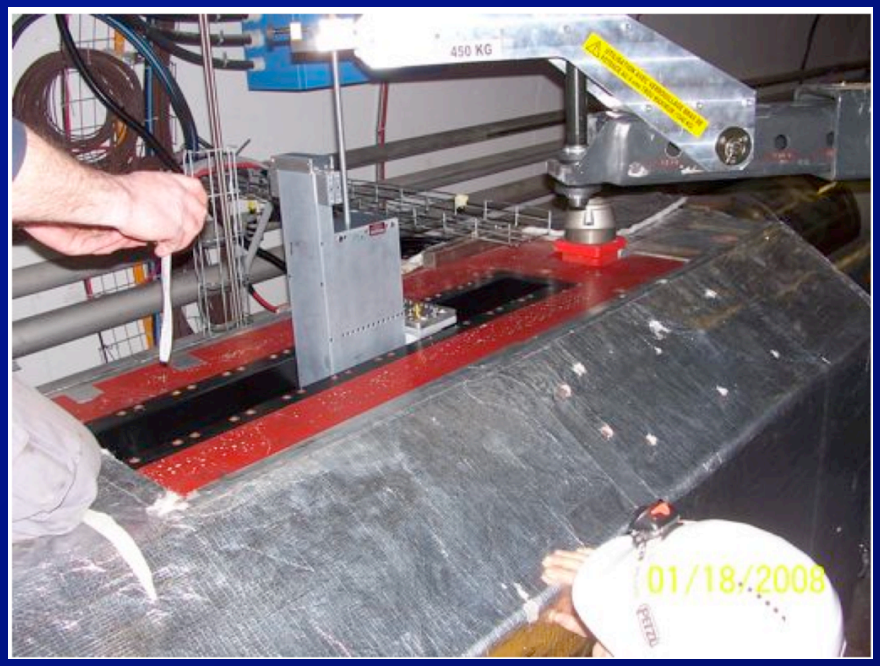
Motivation (2)

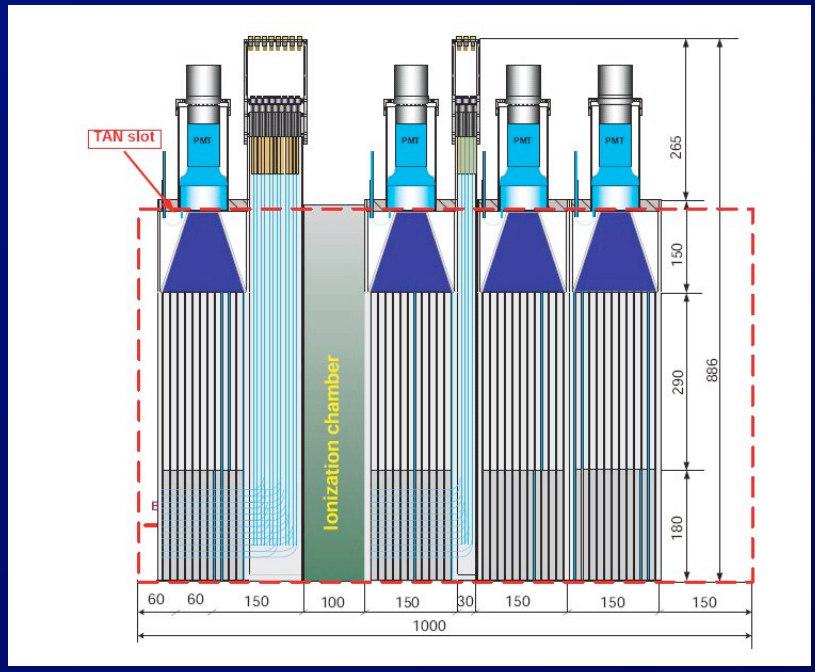
- "Obvious" answer:
  - Measure bremsstrahlung from the stopping nucleons (quarks?)
  - Not a unique idea
    - ⇒R10 by Sandweiss et al
    - ⇒Difficult to measure
- But, suppose we attack the problem differently
  - Don't try to measure at the peak of the spectrum.
    - ⇒Measure very forward at large ω

ATLAS: Zero Degree Calorimeter



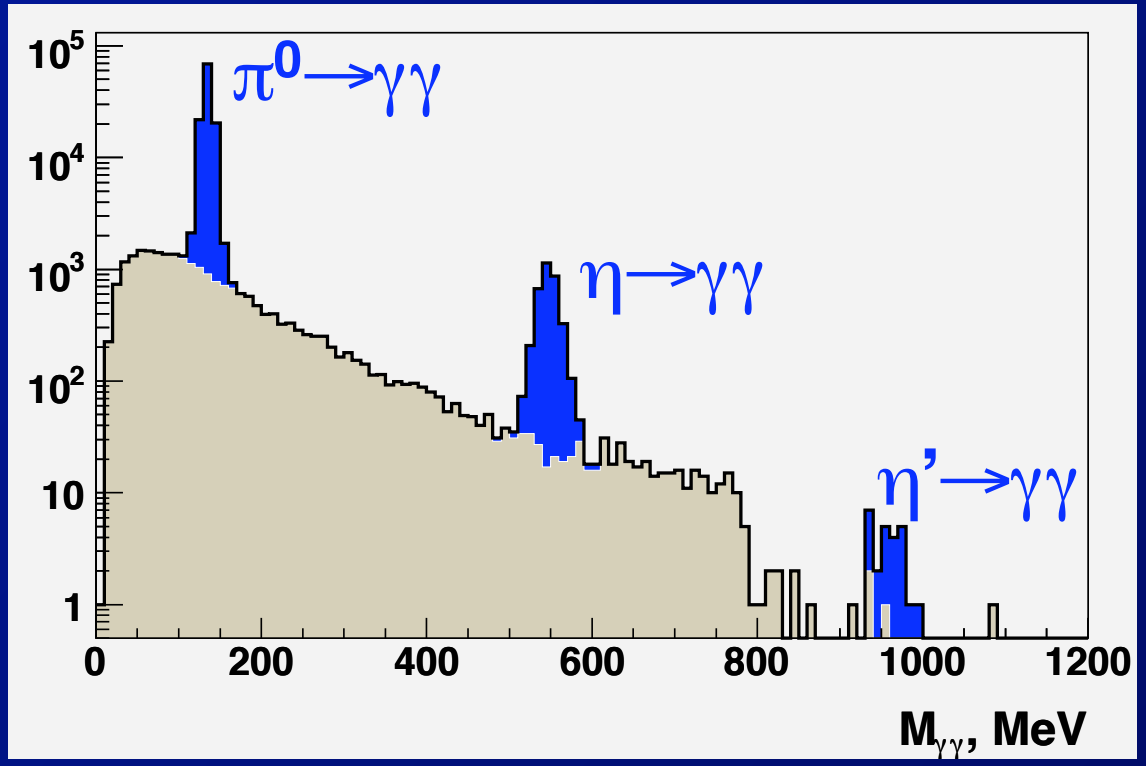


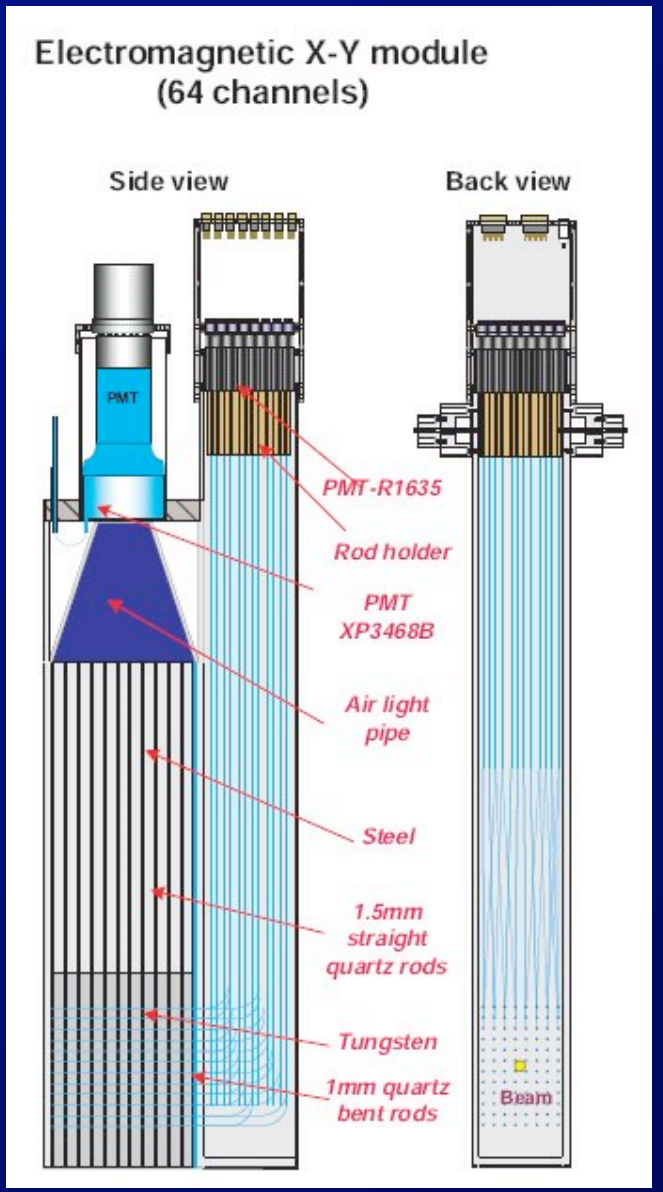




ATLAS: Zero Degree Calorimeter (2)

- **Designed w/ fine-granularity EM module.**
  - Capable of measuring and separating multiple photons/showers.





Bremsstrahlung in ZDC?

- **Key question:**
  - Could we possibly measure bremsstrahlung photons in Pb+Pb at the LHC using (e.g.) ATLAS ZDC
    - ⇒Need energies >~ 100 GeV
- **Here:**
  - Investigation only of bremsstrahlung spectrum, not other experimental problems/limitations.
- **Answer:**
    - ⇒Possibly.

Theory: Kapusta et al

J. Kapusta and S. Wong, Phys. Rev. C59:3317 1999

The formula for computing the classical bremsstrahlung from accelerated charges is well-known [5]. For charges q_i with coordinates $\mathbf{r}_i(t)$, velocities $\mathbf{v}_i(t)$ and accelerations $\mathbf{a}_i(t)$ the intensity and number of photons emitted with frequency ω in the direction $\mathbf{n}$ are

$$\frac{d^2I}{d\omega d\Omega} = \omega \frac{d^2N}{d\omega d\Omega} = |\mathbf{A}|^2 \tag{1}$$

where the amplitude is

$$\mathbf{A} = \sum_i q_i \int_{-\infty}^{\infty} \frac{dt}{2\pi} \exp\left\{i\omega\left(t - \mathbf{n}\cdot\mathbf{r}_i(t)\right)\right\} \frac{\mathbf{n}\times\left[\left(\mathbf{n}-\mathbf{v}_i(t)\right)\times\mathbf{a}_i(t)\right]}{\left(1-\mathbf{n}\cdot\mathbf{v}_i(t)\right)^2}\,. \tag{2}$$

The sum over charges may of course be replaced by an integral when the charge distribution is viewed as continuous.

- **Calculation uses classical formula for bremsstrahlung.**
  - –Applied to protons.
  - –Need r(t) ⇒ v(t), a(t)

⇒Model assumptions

⇒Test (e.g.) Bjorken vs Landau

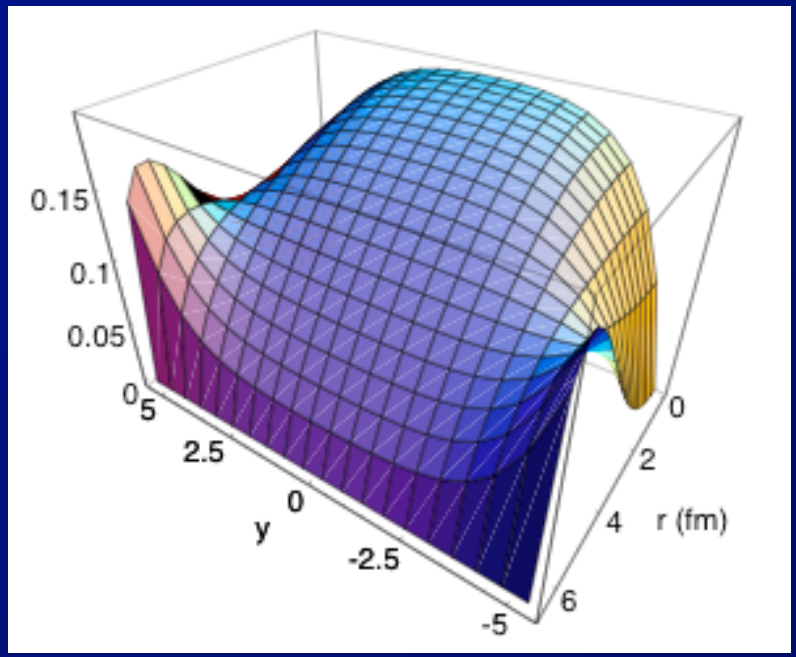
Theory: Kapusta et al, Bjorken

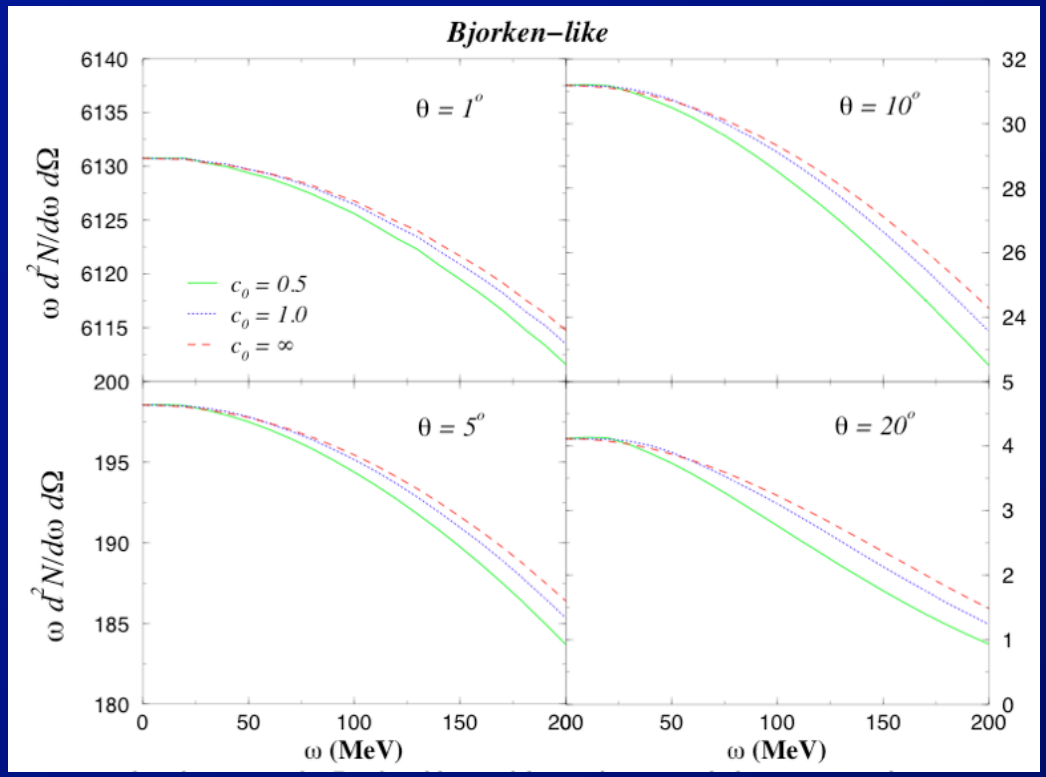
Constant decceleration from initial to final rapidity

$$z(l, r_\perp, t) = \begin{cases} v_0 t & t < 0 \\ v_0 t + a(l, r_\perp) t^2/2 & 0 < t < t_f \\ z(l, r_\perp, t_f) + v_f (t - t_f) & t_f < t\,. \end{cases}$$

$$a(l, r_\perp) = \frac{v_f - v_0}{t_f} = \frac{\tanh y - \tanh y_0}{t_f}\,.$$

Final nucleon rapidity distribution

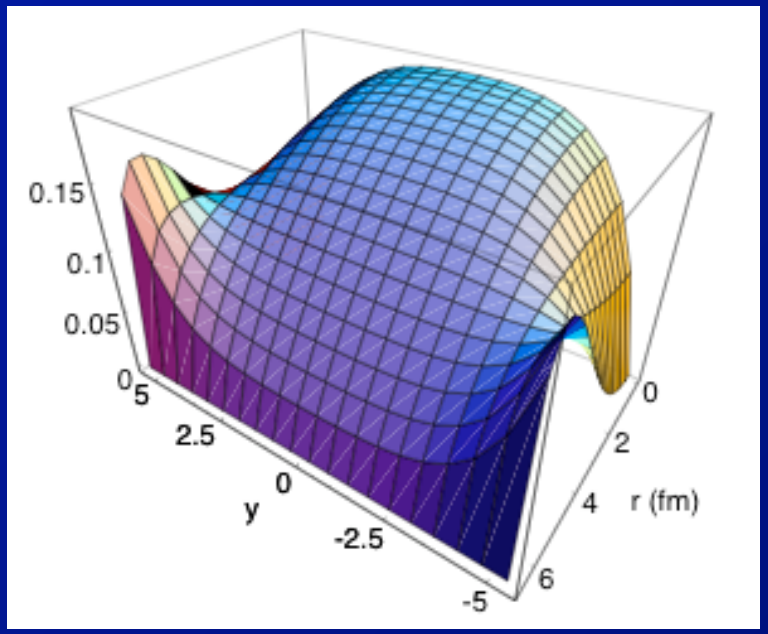


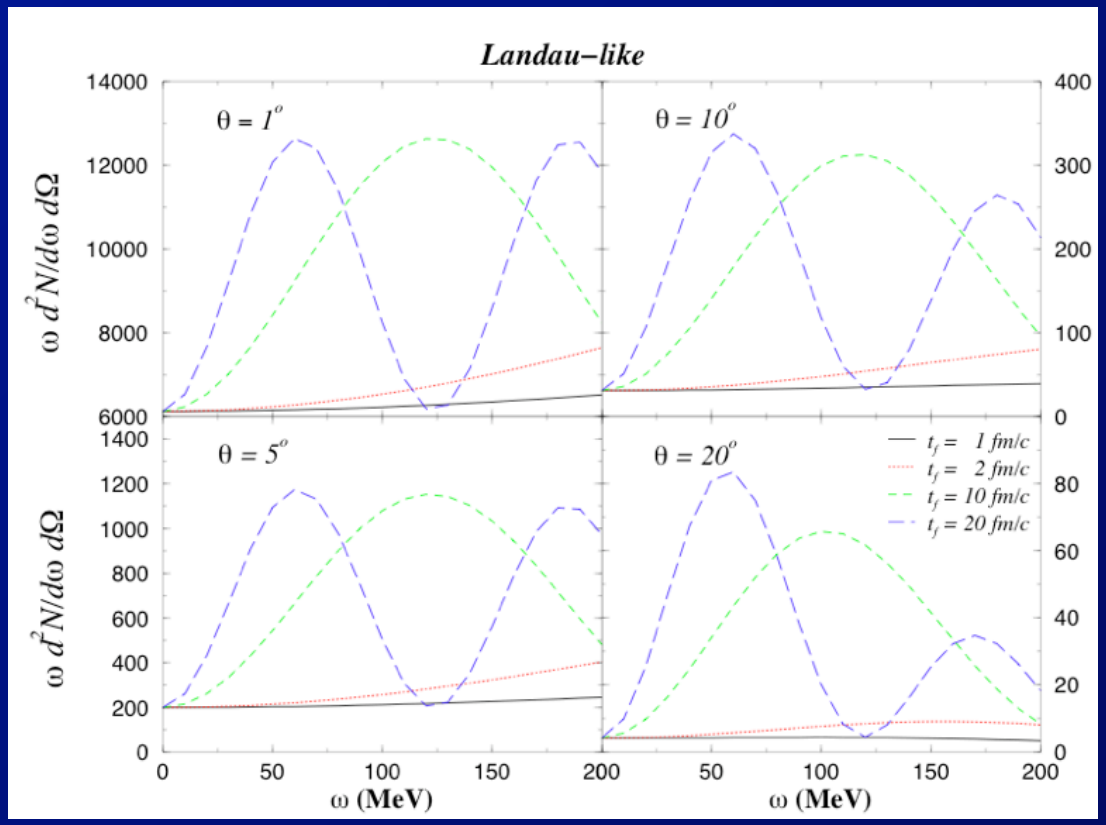


- **Results for modest angles, small photon energies.**

Theory: Kapusta et al, Landau

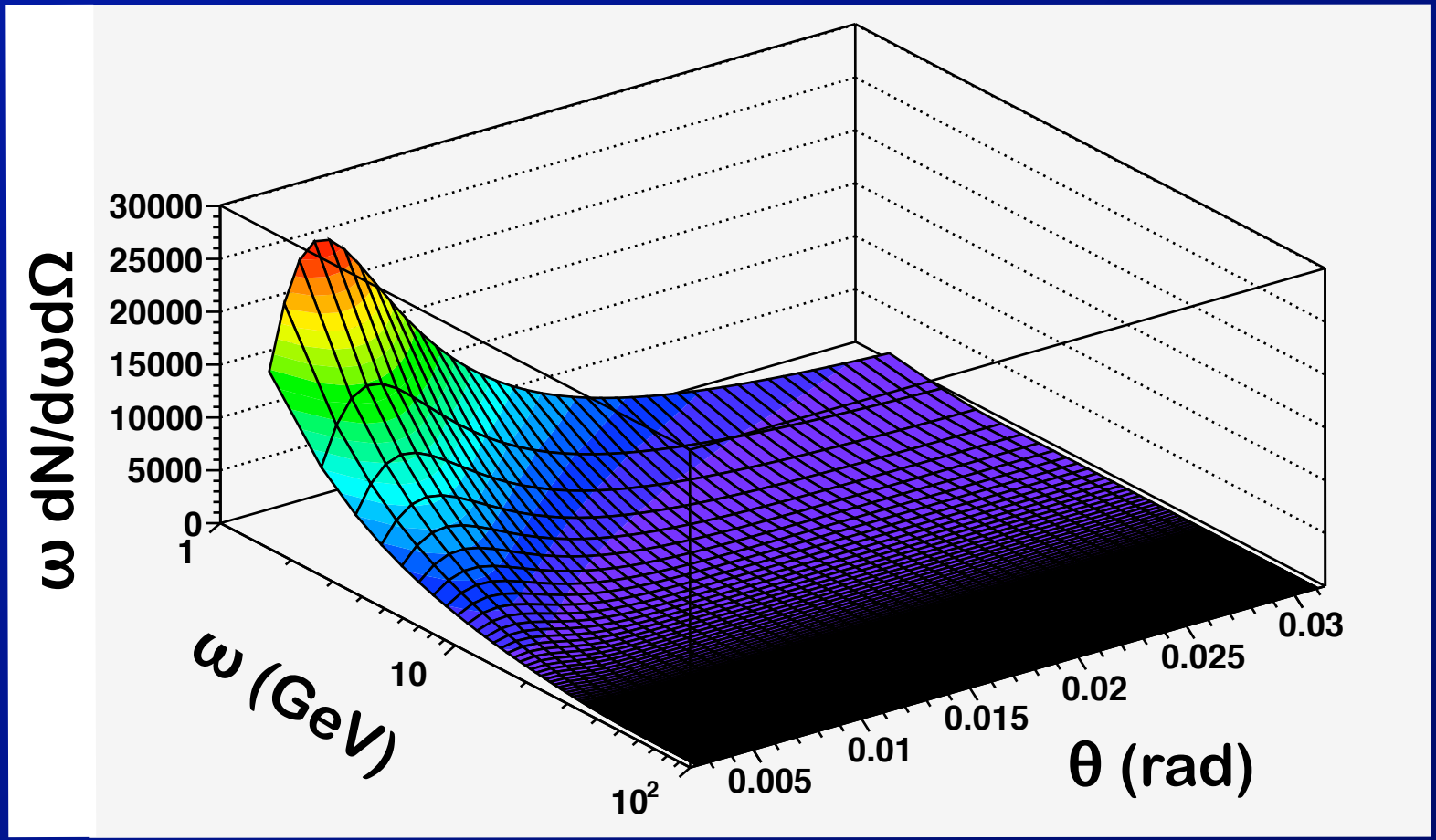
$$a(l, r_\perp) = -v_0\delta(t) + \frac{v_f}{t_f}\theta(t)\theta(t_f - t)$$





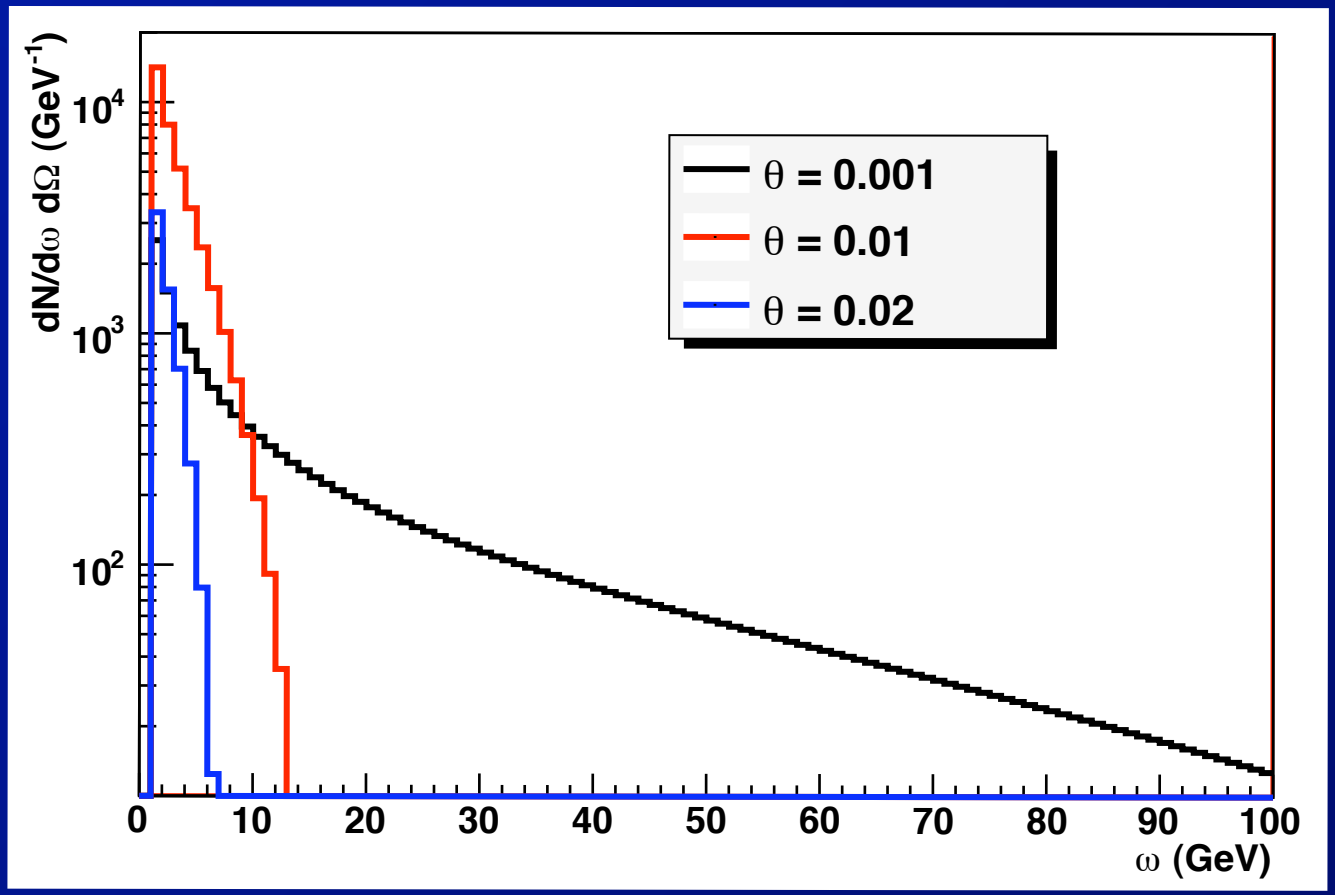
- **Landau IC: sudden stopping and re-acceleration to final rapidity**
  - Note: for "reasonable" t_f get a spectrum peaked at higher ω.

Angerami: Repeat Kapusta Calculation



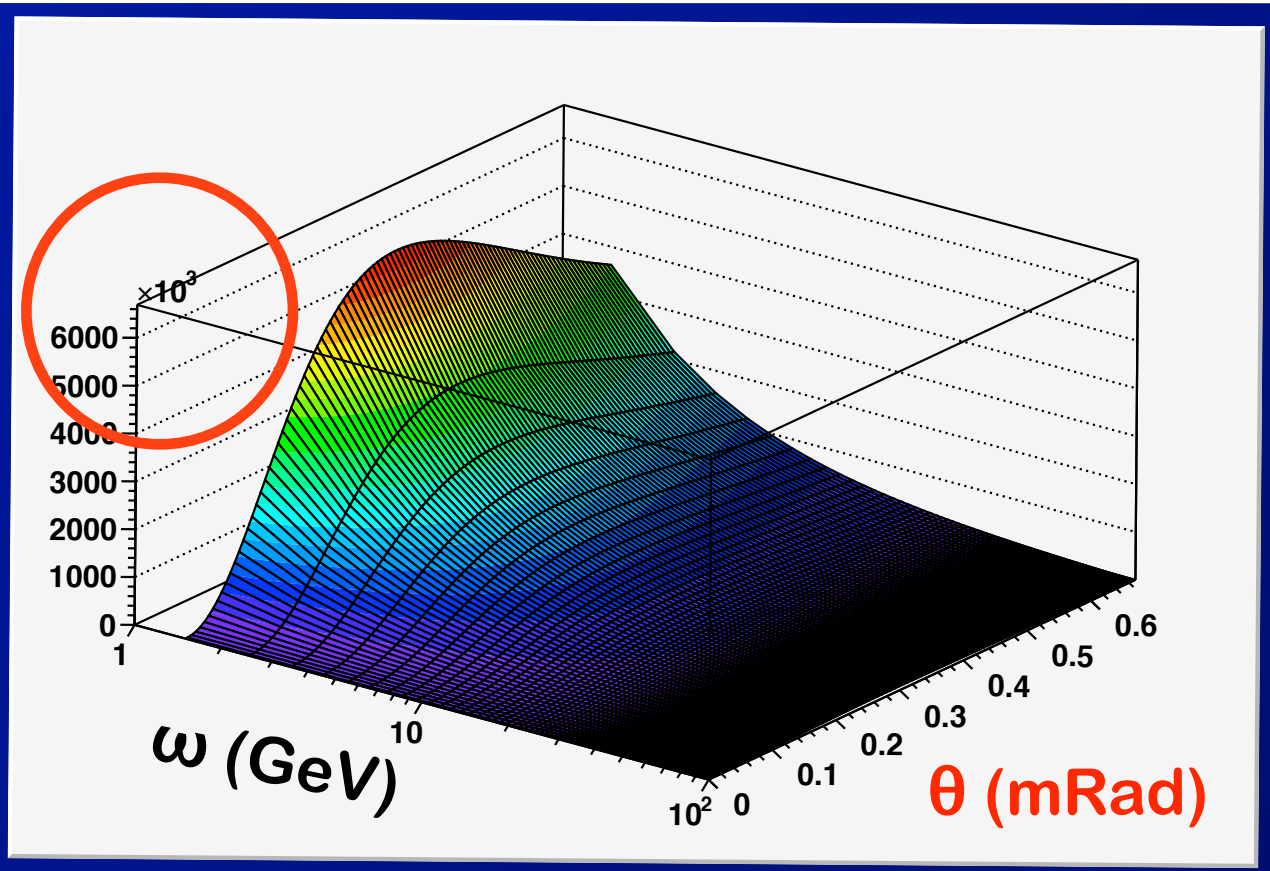
- **Look at photon spectrum over larger energy range (Bjorken scenario)**
  - Spectrum extends to >> 1 GeV.
  - At small angles.

Angerami: Repeat Kapusta Calculation(2)



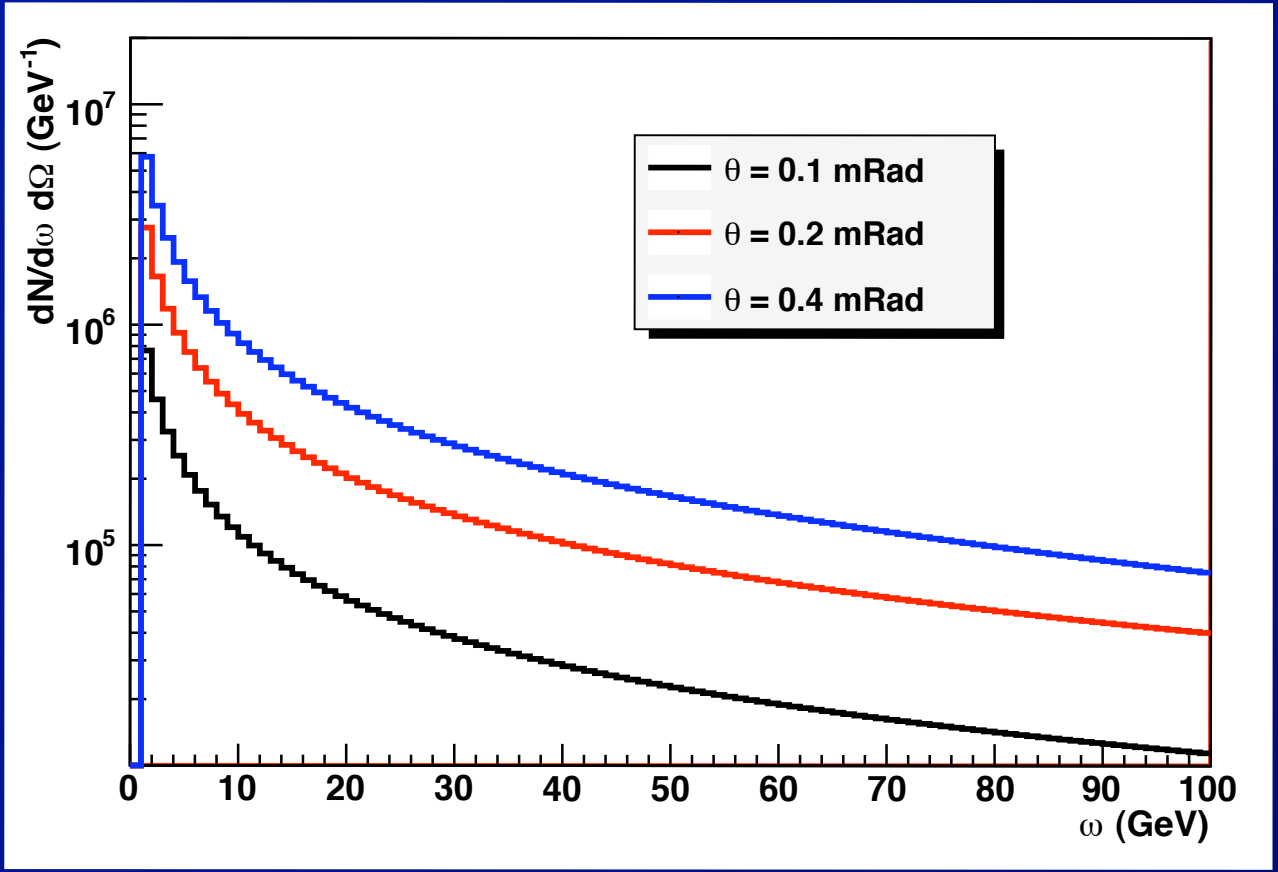
- Look at Bjorken (e.g.) calculation at RHIC energies as a function of angle.
  - ⇒Extension of Bremsstrahlung spectrum to large energy @ small angle.

Angerami: Kapusta Calculation @ LHC



- At small angles (< 1mRad), very stiff photon energy spectrum.
  - Extends into the ~ 100 GeV range that we need for ZDC measurement.

Angerami: Kapusta Calculation @ LHC(2)



- **Energy distribution for different angles.**
  - –Extend well past 100 GeV
  - –ZDC yield multiplied by small dΩ

    ⇒~ 1×10^{-6} ⇒ ~ 0.05/event above 100 GeV

Calculation: considerations

- Landau calculation needs improvement before application to LHC energies (in progress).
- Bremsstrahlung from nucleons?
  - Depending on k_T, presumably sensitive to quarks not nucleons.
- Can forward γ bremsstrahlung be incorporated into CGC (e.g.)?
- Measuring bremsstrahlung in ATLAS ZDC looks plausible

  ⇒Needs real experimental simulation.